Technical Meeting on MQXFB07 : Assembly and Pre-load target

Susana Izquierdo Bermudez, Penelope Quassolo on behalf of MQXF team

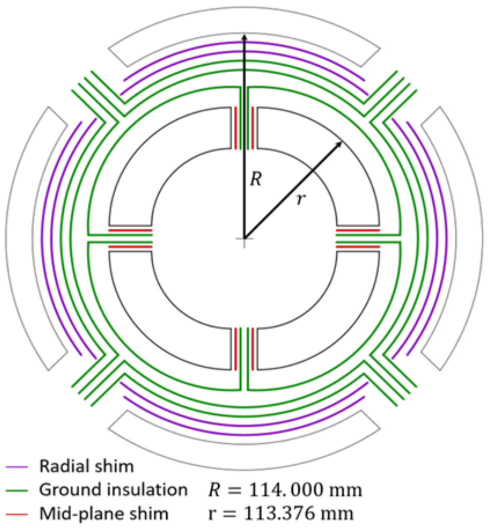
11/09/2024

Technical Meeting MQXFB07 Assembly (September 11, 2024) · Indico (cern.ch)

Shimming plan

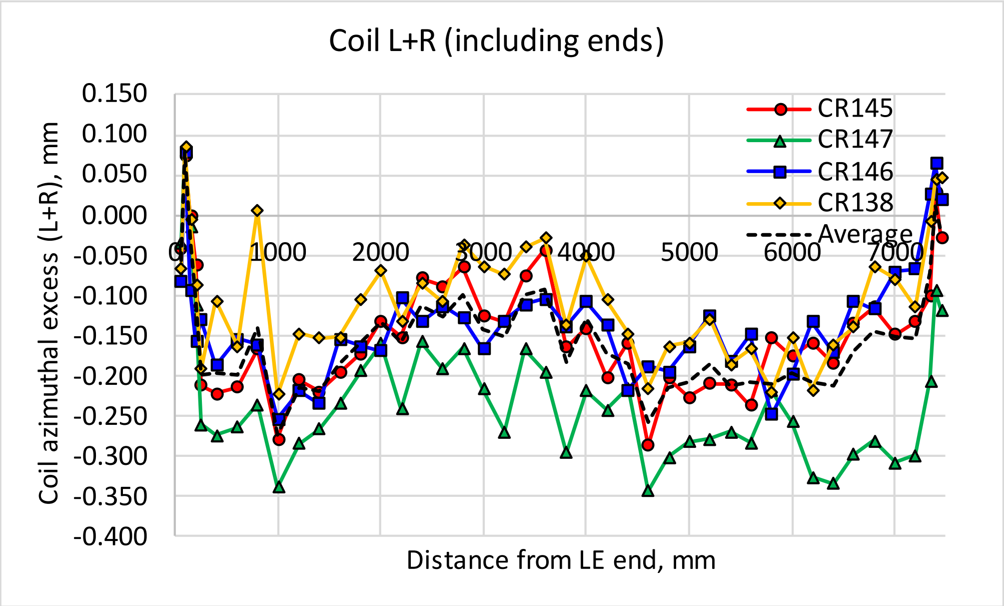
Shimming strategy - Mid-plane and radial shims

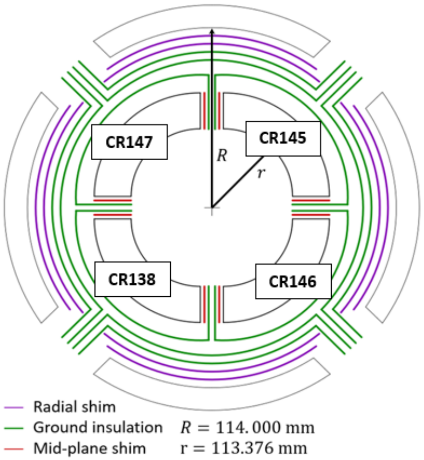
- **Strategy:** coils with different azimuthal sizes are shimmed to match the largest one. If all coils are smaller than nominal size, they are shimmed to match the latter value. Shimming is placed on the mid-plane.
- The resulting variation of outer radius is compensated by adding/removing radial shims*.
- 0.125 mm of radial shims are removed systematically to improve contact on the mid-plane between collar and coil → experience from LARP and MQXF short models
  - So-called “LQ effect”



*The ground insulation layers must be respected. Targeting as a baseline to remove at least one of the radial shims, coil average size is exceeded when $L+R_{average}$ > 200 µm. Non-optimal contact with the collars.

MQXFB07: Coil Size + midplane shim



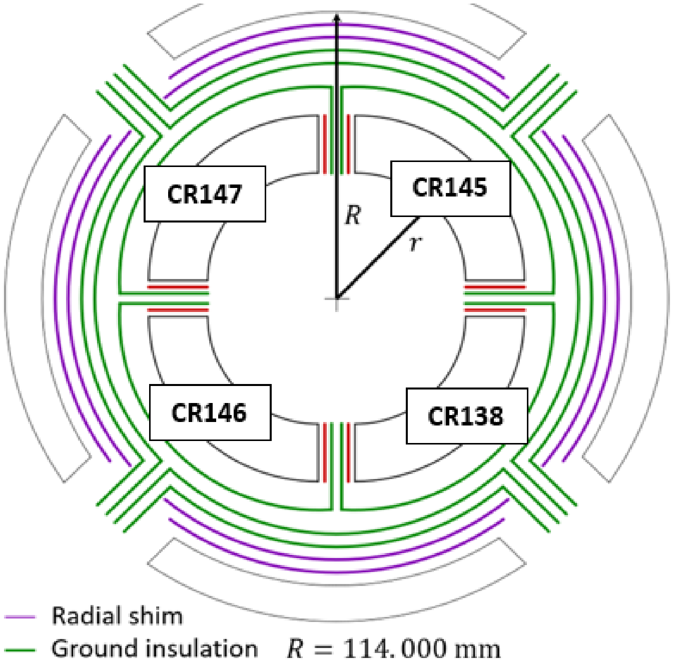


		Average (Excluding ends)	Rounded value
Azimuthal excess L+R [µm]	CR145	-166	-150
	CR147	-254	-250
	CR146	-154	-150
	CR138	-122	-150

	Shim
CR145	150
CR147	250
CR146	150
CR138	150

MQXFB07 largest coil (CR138) is smaller than the nominal azimuthal size, so all the coils are shimmed to the nominal azimuthal size. CR147 is the smallest.

MQXFB07 -175 um shimming plan



125 µm ground insulation

75 µm radial shim

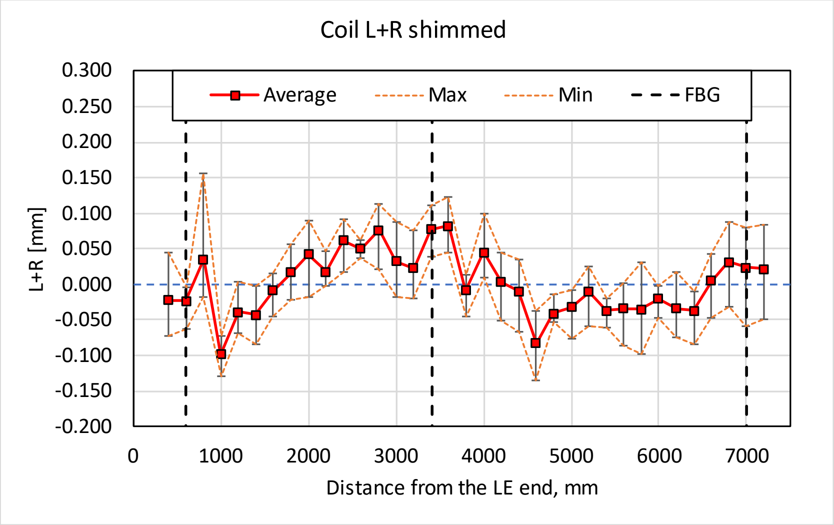
Midplane shimming

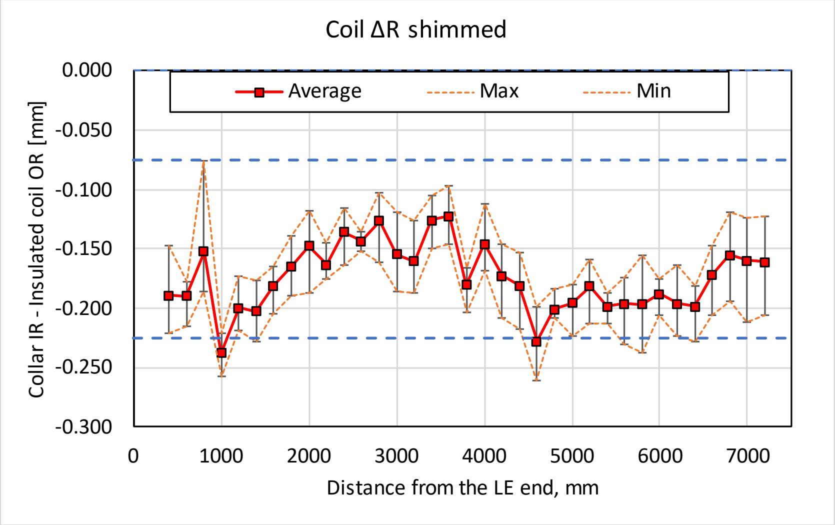
- -175 µm removed from radial shimming to compensate for the azimuthal size.

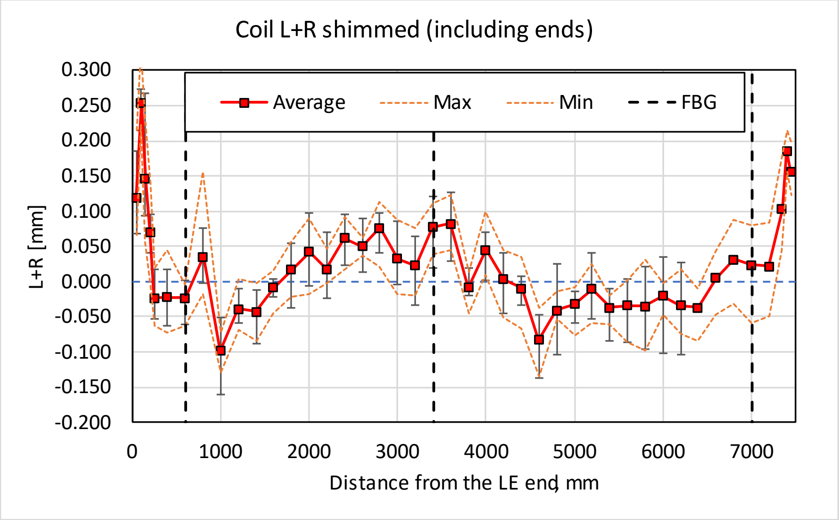
Radial shim [µm]		-175	-175	-175	-175
Azimuthal shim [µm]		CR145	CR147	CR146	CR138
		150	250	150	150
		AVE	LE	CE	RE
Azimuthal excess L+R+shim [µm]	CR145	-16	-62	76	3
	CR147	-4	-13	82	-58
	CR146	-4	-4	40	80
	CR138	28	-8	111	69
	Average	1	-22	77	24
	Average incl. ends	7	25	18	46
		AVE	LE	CE	RE
Coil pack radial size [µm]	CR145	-185	-214	-127	-173
	CR147	-178	-183	-123	-212
	CR146	-178	-178	-150	-124
	CR138	-157	-180	-104	-131
	Average	**-174**	**-189**	**-126**	**-160**
Excluding ends		**AVE**	**MAX**	**MIN**	**STD**
Azim. Exc. L+R+shim [mm]		**0.001**	**0.082**	**-0.099**	**0.043**
Coil pack radial size [mm]		**-0.174**	**-0.123**	**-0.238**	**0.027**

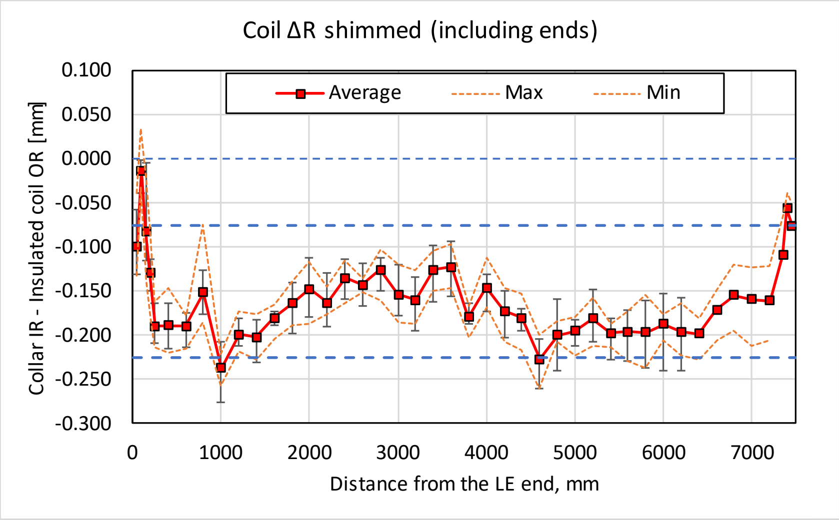
MQXFB07 -175 um shimming plan

Azimuthal and radial size

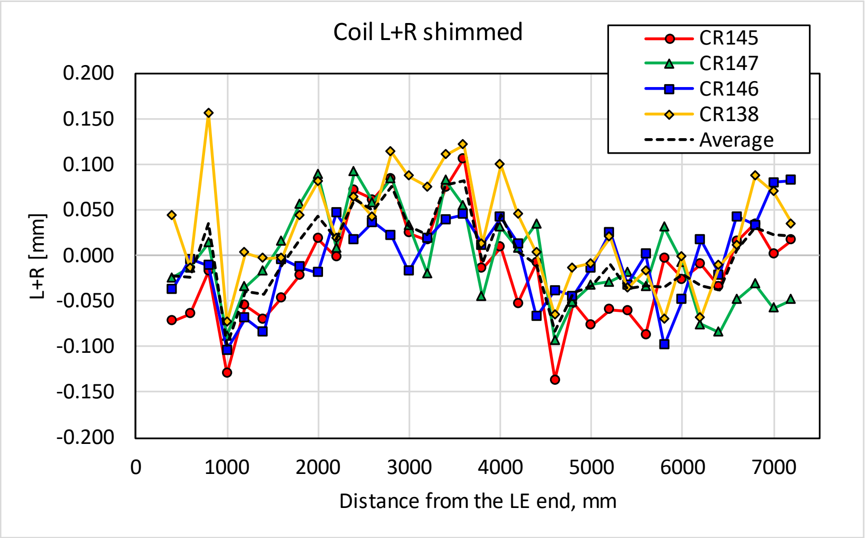




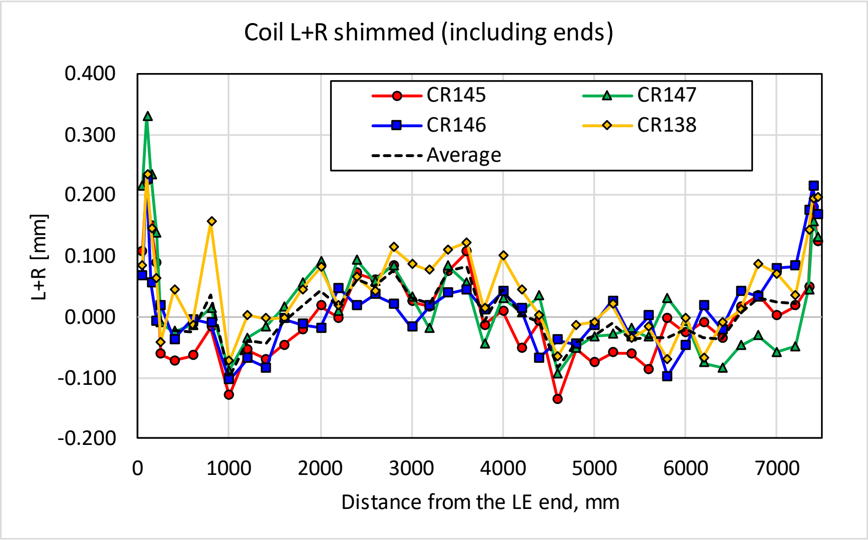




MQXFB07



Coil L+R shimmed
CR145
CR147
CR146
CR138
Average
L+R [mm]
0.200
0.150
0.100
0.050
0.000
-0.050
-0.100
-0.150
-0.200
0
1000
2000
3000
4000
5000
6000
7000
Distance from the LE end, mm

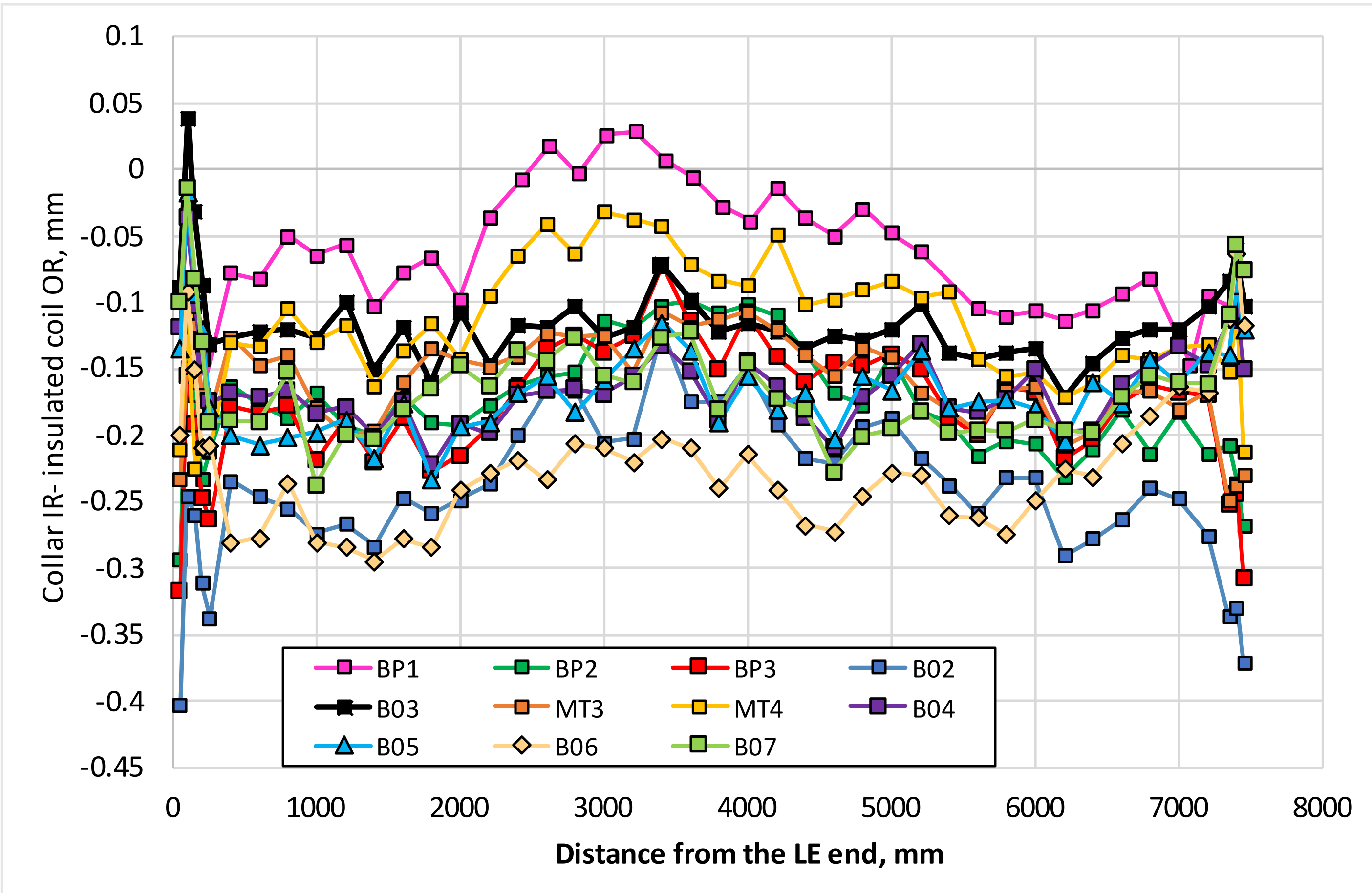


Coil L+R shimmed (including ends)
CR145
CR147
CR146
CR138
Average
L+R [mm]
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
0
1000
2000
3000
4000
5000
6000
7000
Distance from the LE end, mm

MQXFB07 -175 um shimming plan

Radial size and comparison to previous magnets

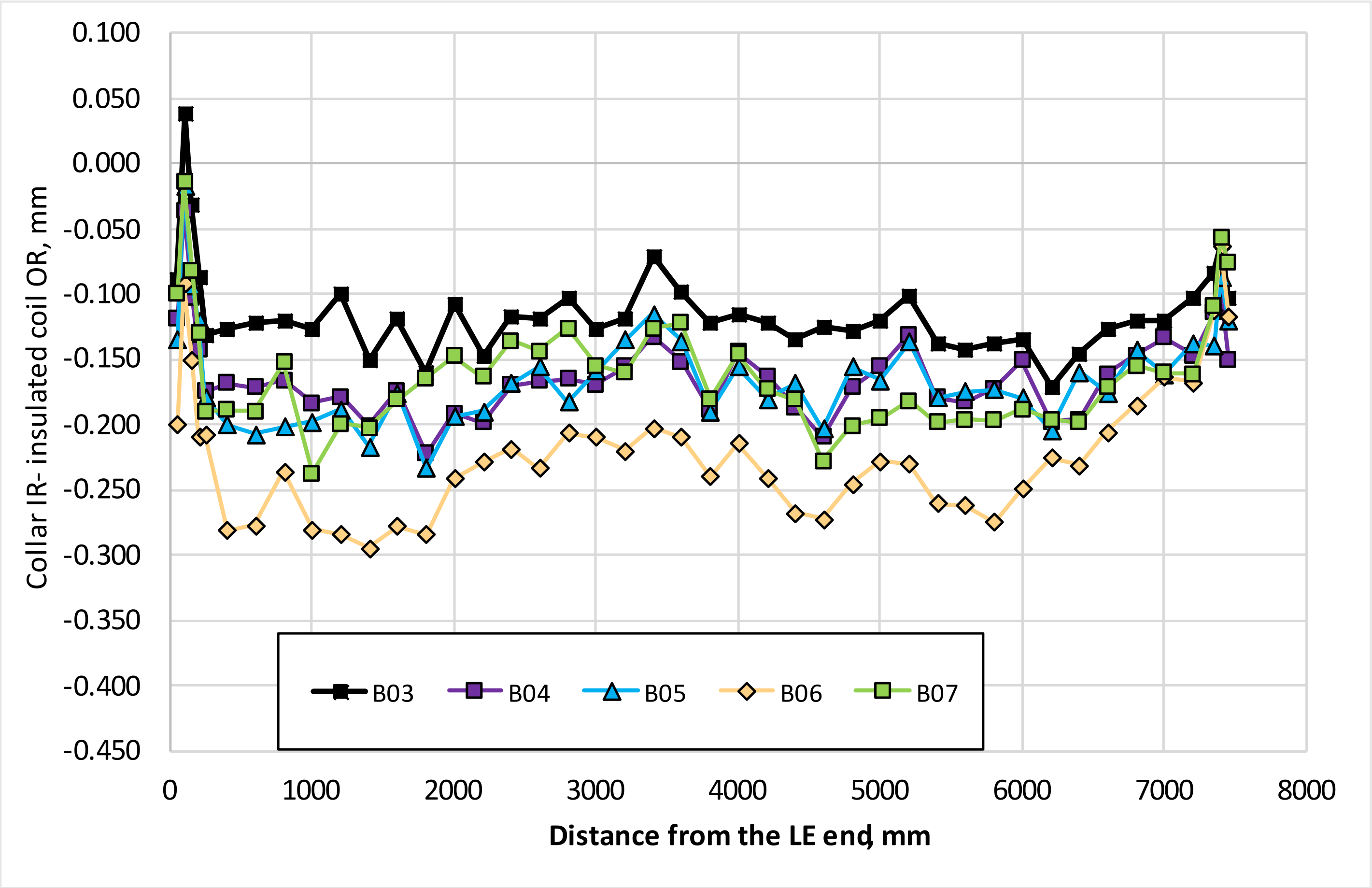
The radial shim is defined in order to have a coil pack dimensions close to B04/B05. The ends have a similar size to previous magnets.



MQXFB07 -175 um shimming plan

Radial size and comparison to previous magnets

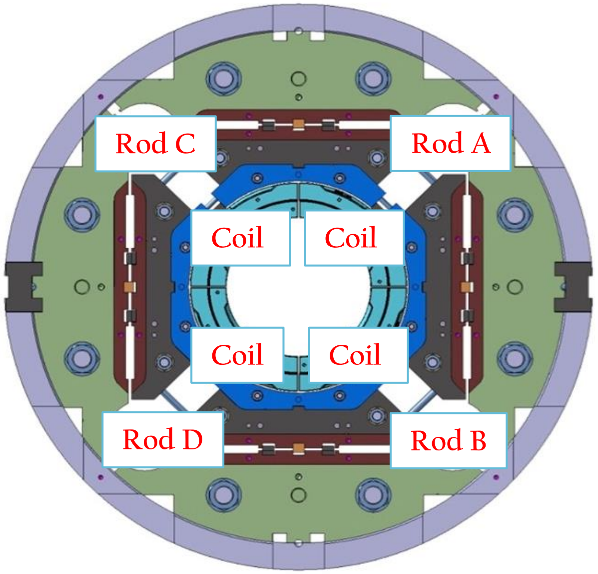
The coil pack size is really similar for all the magnets with the 'new generation' coils. B06 size is smaller on purpose, to have a conservative size of the ends, similar to the previous magnets.



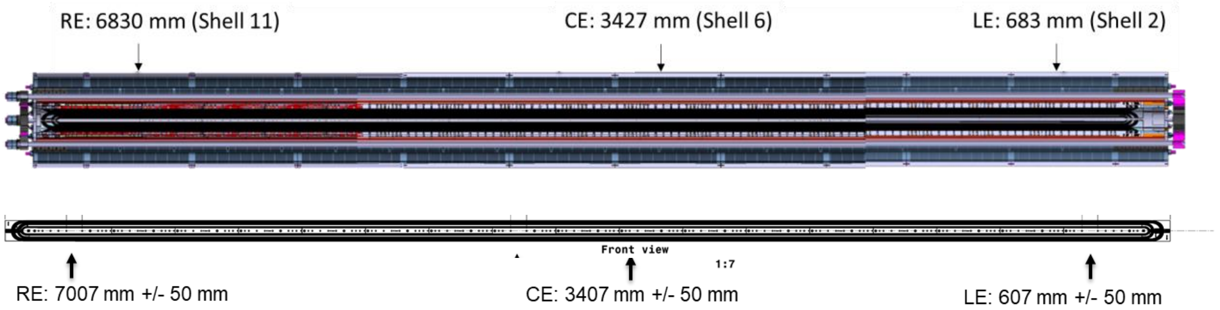
Pre-load targets

Instrumentation overview

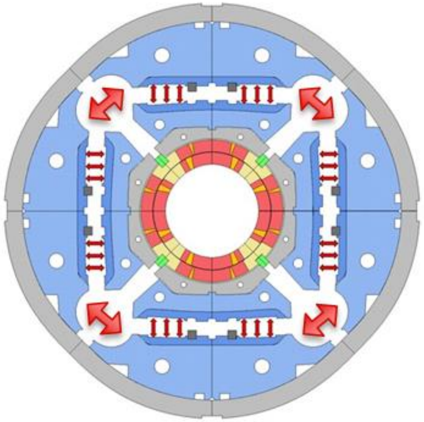
Magnet component	Number & Directions	Bridge configuration	Type
SHELL	12 (Θ) 12 (Z)	SG quarter bridge + thermal compensator	Cr – Ni / Polyimide HBM LC11-6/350
COILS	12 (Z) 12 (Θ)	FBG (+ temperature sensor to compensate T effect)	FemtoSecond® 4 arrays with 2 FBG
RODS	4 (Z)	SG full bridges	Cr – Ni / Polyimide HBM LC11-3/350



- Coil and shell are instrumented in three axial locations (LE (lead), CE (center), RE (Return))



Azimuthal pre-load target (from B03 on)

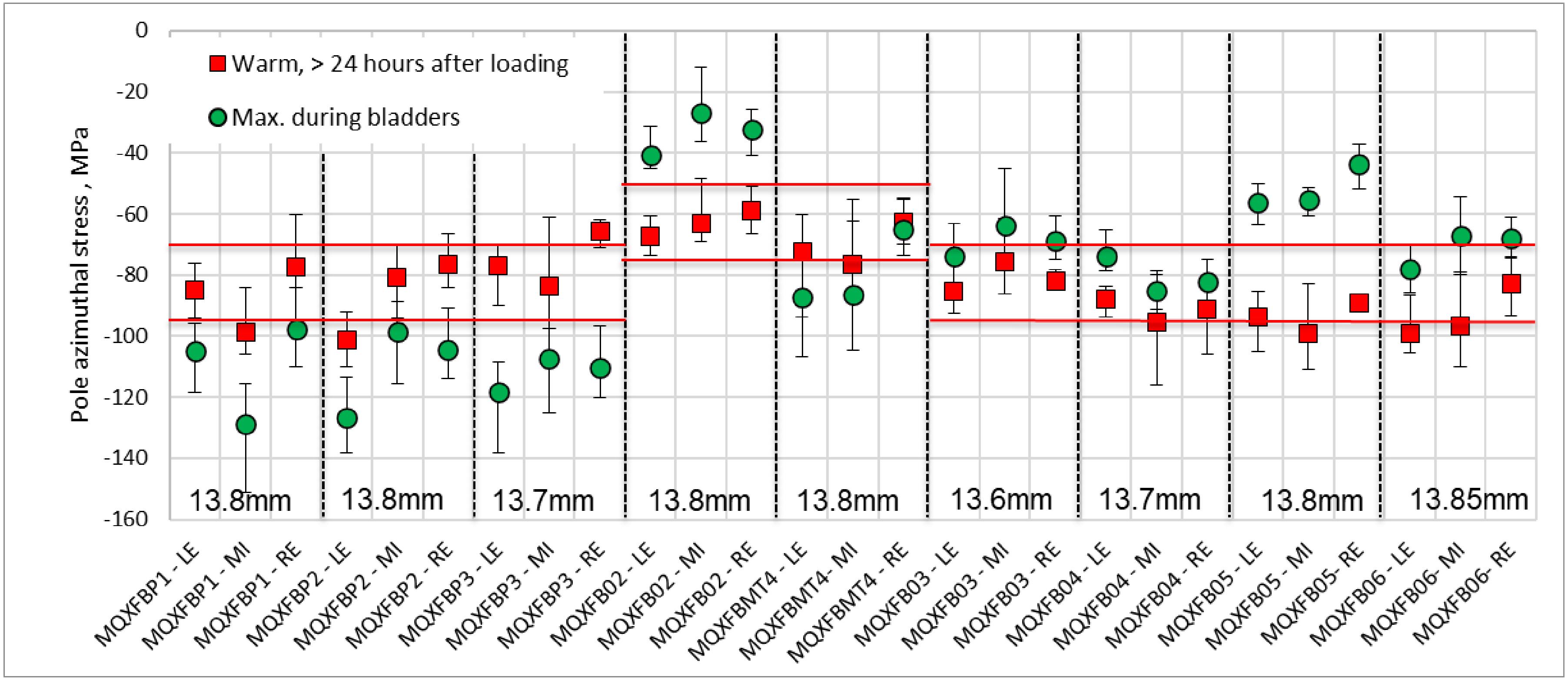


- The allowable peak stress in the coil during loading is -110 MPa, achievable thanks to the new loading procedure with auxiliary bladders (AUP has -135 MPa as maximum allowable stress).

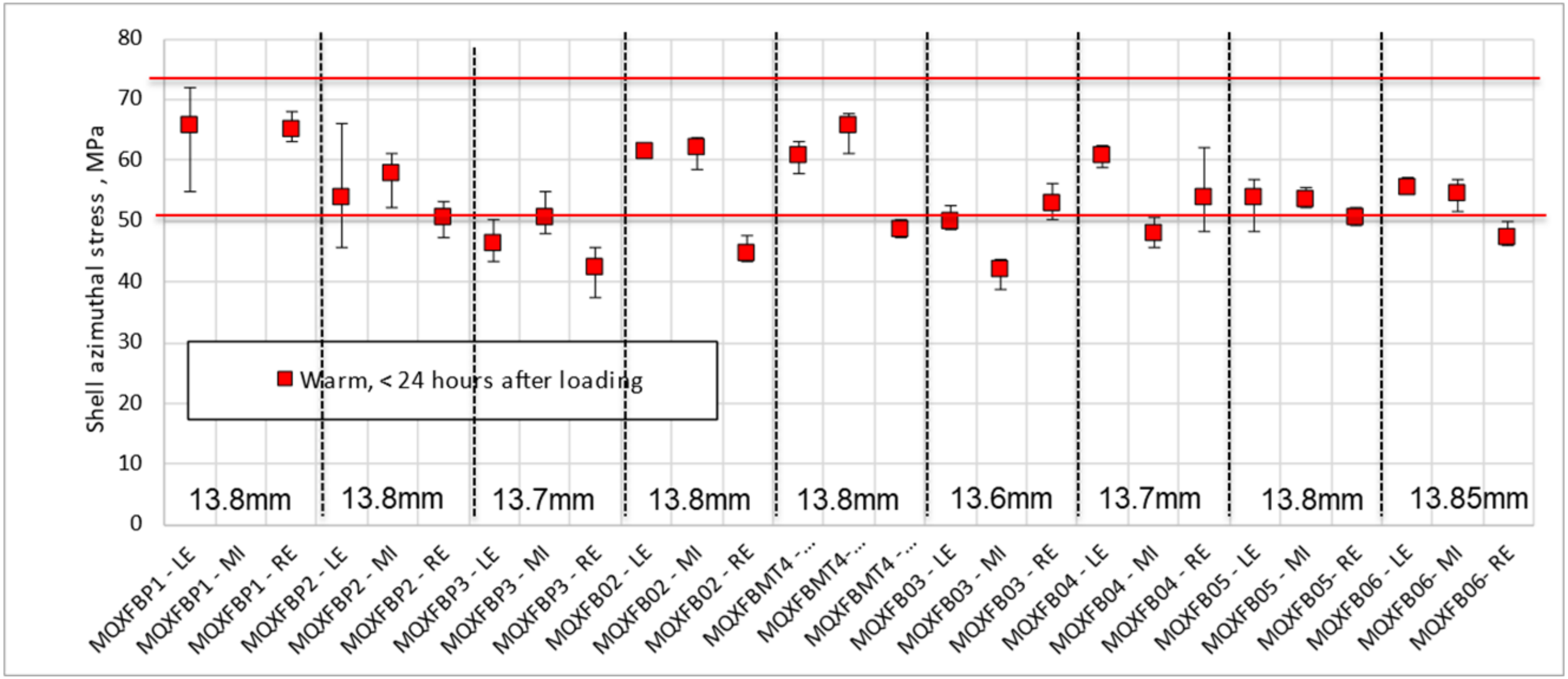
- The target room temperature preload for MQXFB03/B04/B05/B06:
  - Average shell stress: 58 ± 6 MPa;
  - Average pole coil stress: -80 ± 10 MPa
  - Rod strain: 650 με
  - This is a target not a requirement, and in case the maximum allowable peak stress in the conductor (110 MPa) is reached, the average pre-load will be lowered accordingly to fulfill the peak stress requirement

- With the new welding procedure (applied from MQXFBP3), we expect no increase on the azimuthal stress of the coils during welding

RT: Targets vs achieved



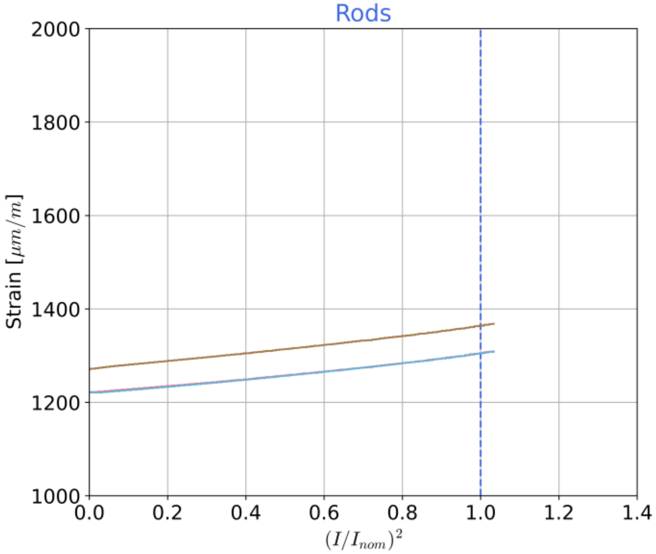
RT: Targets vs achieved



Axial pre-load

- Small change of strain on the rods during powering → longitudinal stiffness of the structure is as expected, and overall behaviour is like what we have seen in MQXFS and MQXFA
- Similar behaviour to the previous magnets, although now the magnet is mostly quenching in the ends
- Proposal for MQXFB07: keep the same target as all previous magnets: i.e., 650 με after loading

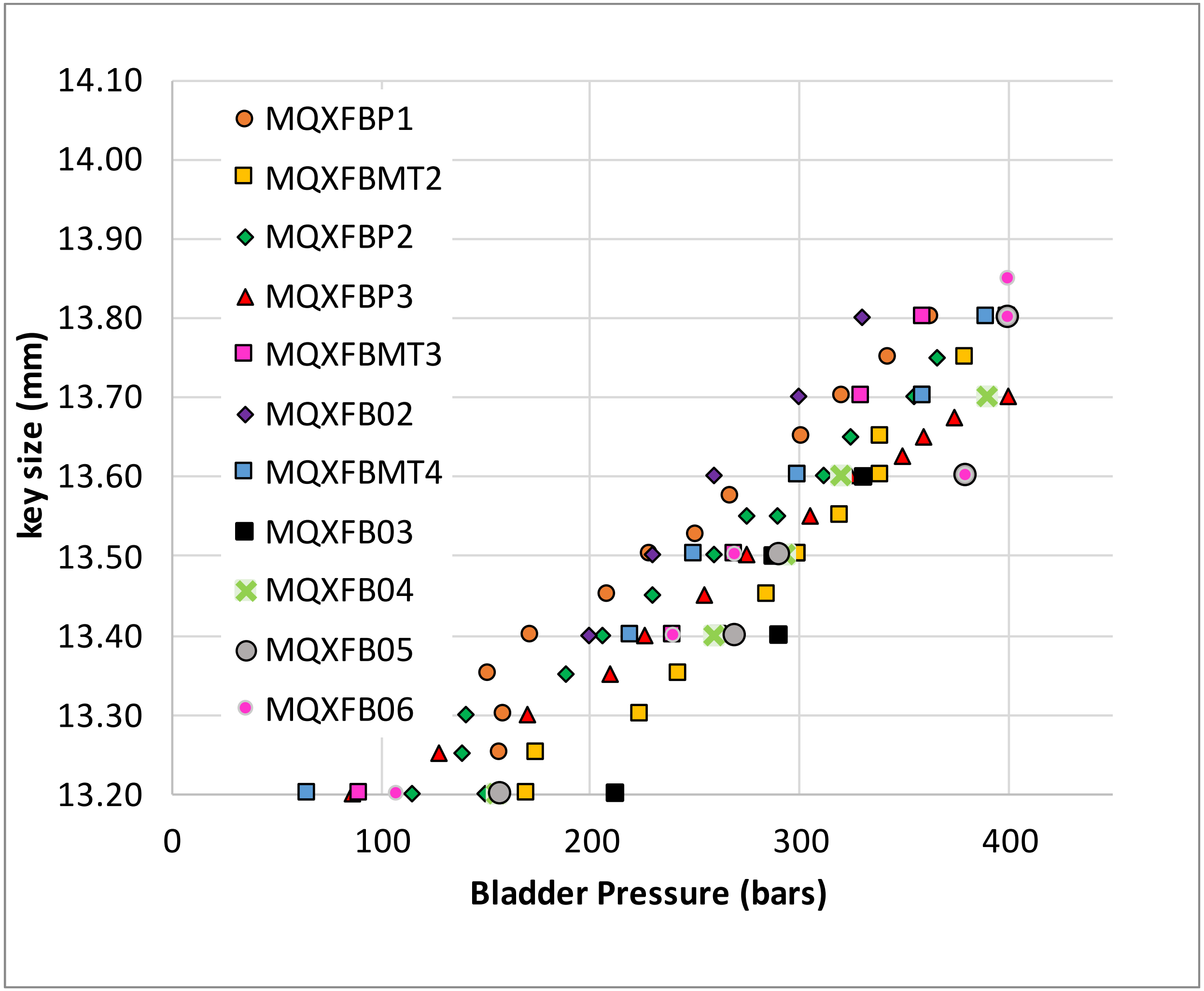
Delta rods strain during powering MQXFB03



		Δ Rod Strain CD FEM [με]	Δ Rod Strain 16.23 kA FEM [με]	Δ Rod Strain CD [με]	Δ Rod Strain 16.23 kA [με]
Magnet	MQXFBP1	670	35	452	70
	MQXFBP2			461	55
	MQXFBP3			517	75
	MQXFB02			537	75
	MQXFB03			560	85

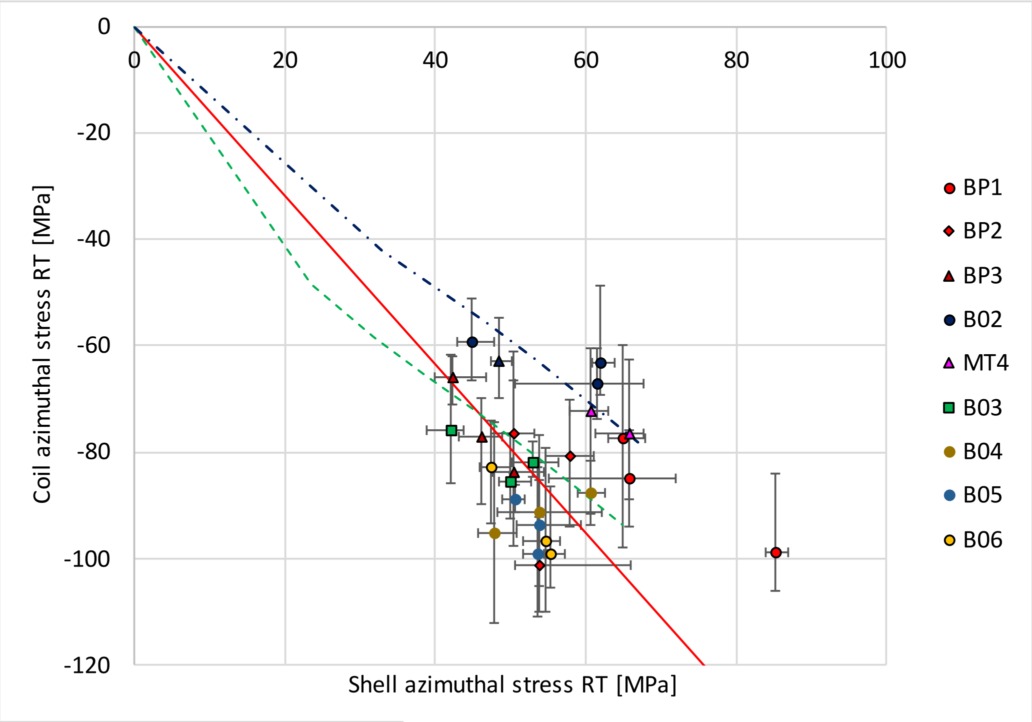
Bladder pressure

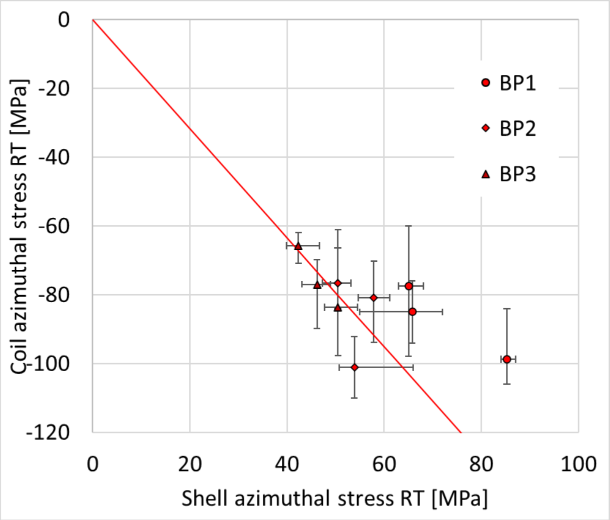
- The other observable we have during assembly is the bladder pressure
  - Assembly tolerances play a role, on some occasions, you need 20-30 bars to overcome a singularity in the structure
  - Requirement: never exceed 400 bars

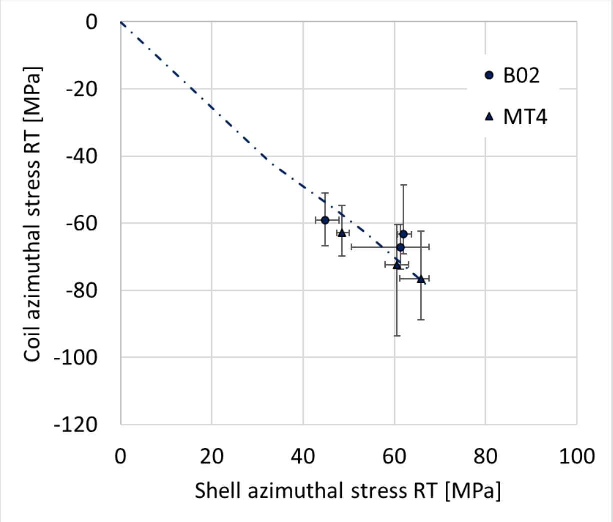


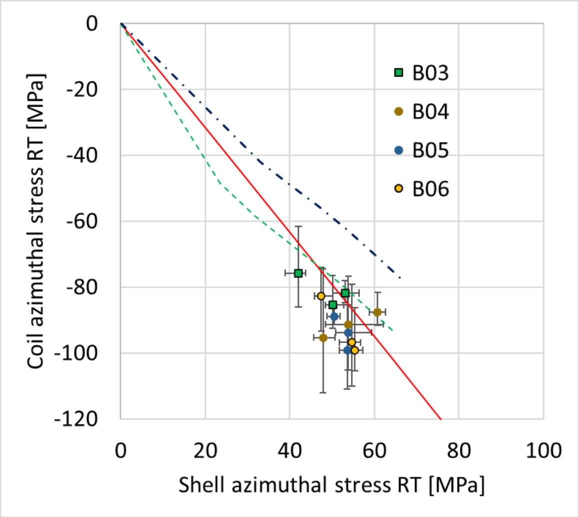
RT transfer function

- So far, relatively good agreement between expected transfer function and measured transfer function
  - In B02/MT4 we show the change of slope due to the new loading procedure
  - In B03/B04/B05/B06 we are closer to the original slope due to the 'new coil geometry'





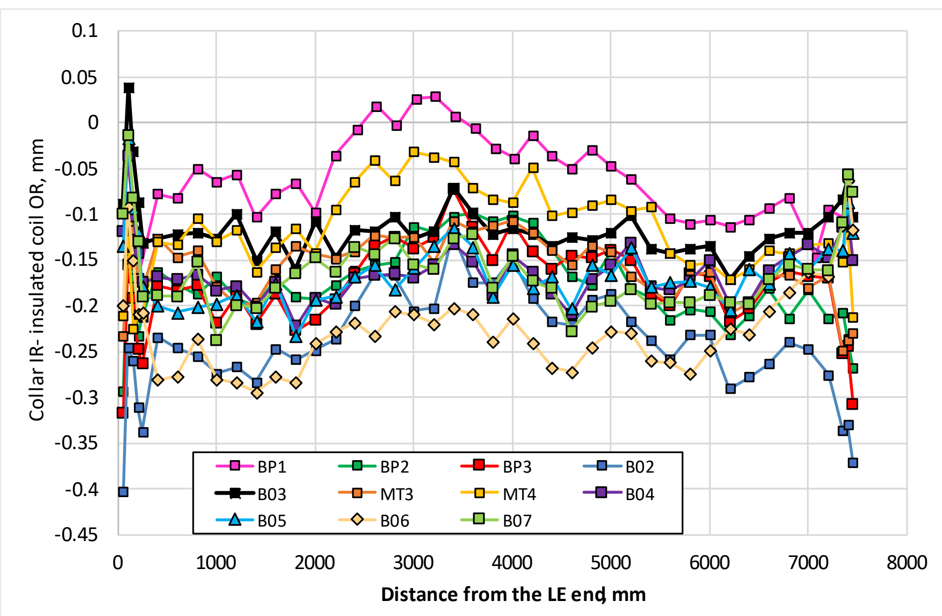


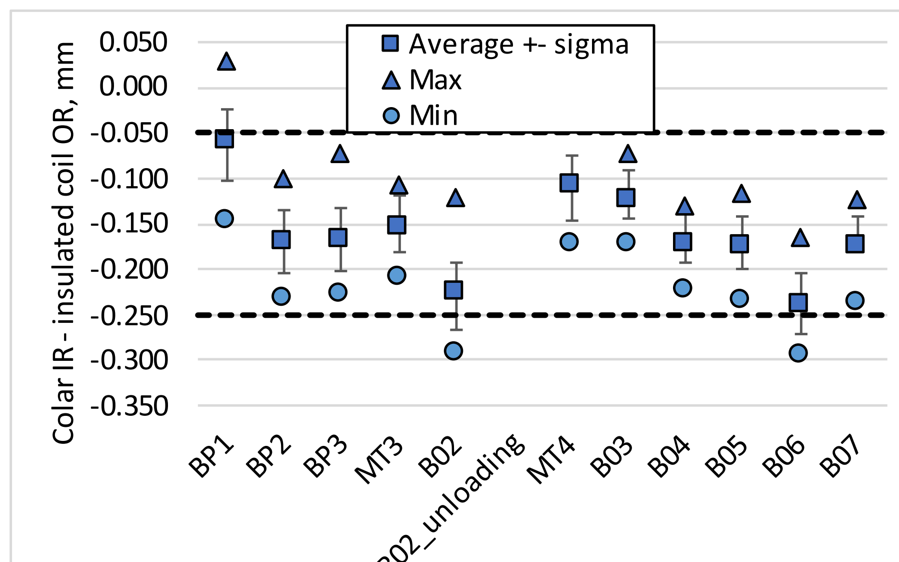


Loading key target

- The target is to have a key 13.8 mm
  - At CERN we don't have finer granularity

	Coil pack radial size deviation							Loading key thikness	Coil pack radial size deviation + loading key thikness -13.8					
	RE	MI	LE	AVE SS	MAX SS	MIN SS	STD SS		RE	MI	LE	AVE SS	MAX SS	MIN SS
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
BP1	-0.049	0.008	-0.082	-0.058	0.029	-0.147	0.045	13.800	-0.049	0.008	-0.082	-0.058	0.029	-0.147
BP2	-0.177	-0.102	-0.185	-0.168	-0.099	-0.232	0.037	13.800	-0.177	-0.102	-0.185	-0.168	-0.099	-0.232
BP3	-0.167	-0.074	-0.183	-0.166	-0.072	-0.227	0.035	13.700	-0.267	-0.174	-0.283	-0.266	-0.172	-0.327
B02	-0.249	-0.123	-0.246	-0.225	-0.121	-0.291	0.041	13.800	-0.249	-0.123	-0.246	-0.225	-0.121	-0.291
MT4	-0.133	-0.043	-0.132	-0.107	-0.031	-0.171	0.039	13.800	-0.133	-0.043	-0.132	-0.107	-0.031	-0.171
B03	-0.119	-0.072	-0.131	-0.124	-0.072	-0.172	0.019	13.600	-0.319	-0.272	-0.331	-0.324	-0.272	-0.372
B04	-0.134	-0.133	-0.171	-0.171	-0.131	-0.222	0.022	13.700	-0.234	-0.233	-0.271	-0.271	-0.231	-0.322
B05	-0.160	-0.116	-0.207	-0.174	-0.115	-0.233	0.026	13.800	-0.160	-0.116	-0.207	-0.174	-0.115	-0.233
B06	-0.164	-0.203	-0.276	-0.239	-0.164	-0.294	0.033	13.850	-0.114	-0.153	-0.226	-0.189	-0.114	-0.244
B07	-0.16	-0.12586	-0.1887	-0.174	-0.123	-0.238	0.027	13.800	-0.160	-0.126	-0.189	-0.174	-0.123	-0.238

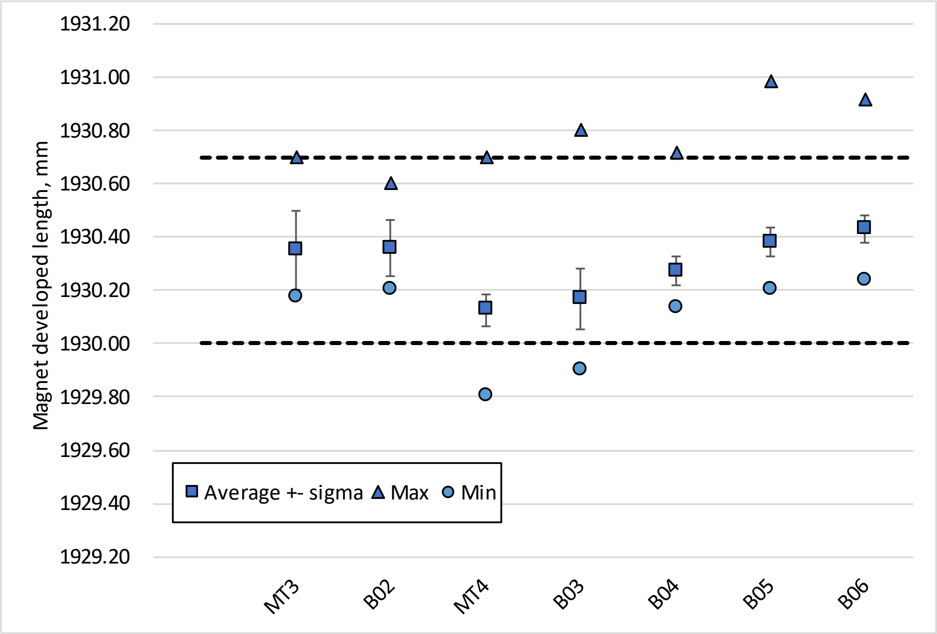




'Straight section' only, i.e., from 400 mm to 7200 mm

Magnet outer developed length

- **In the middle of the aluminium shells, the developed length after loading shall be 1930.2 mm +0.5/-0.2 mm**
  - For a pole pre-stress of 80 MPa, the expected increase of circumference is 1.2 mm in the middle of the aluminium shells, 1.6 mm in the extremities
  - Remark: these measurements are done with a pi-tape, precision ≈ 0.2 mm
  - This info is used for the pairing for the stainless steel shells for welding (see for example MQXFBMT4, EDMS 2847270)



Summary

- Target for MQXFB07: reproduce MQXFB05 pre-load conditions (see EDMS 3064348)
- The target loading key thickness is 13.8 mm
- The target room temperature preload:
  - Average shell stress: 58 ± 6 MPa;
  - Average pole coil stress: - 80 ± 10 MPa
  - Rod strain: 650 με
  - This is a target not a requirement, and in case the maximum allowable peak stress in the conductor (110 MPa) is reached, the average pre-load will be lowered accordingly to fulfill the peak stress requirement
- Based on the experience gained with MQXFB assemblies, a series of observables are monitored along the assembly and compared to previous magnets to verify at every step that we reach our targets (EDMS 2872430)
  - Here we focus on geometrical and strain measurements, but field quality is also closely monitored, see additional slides.

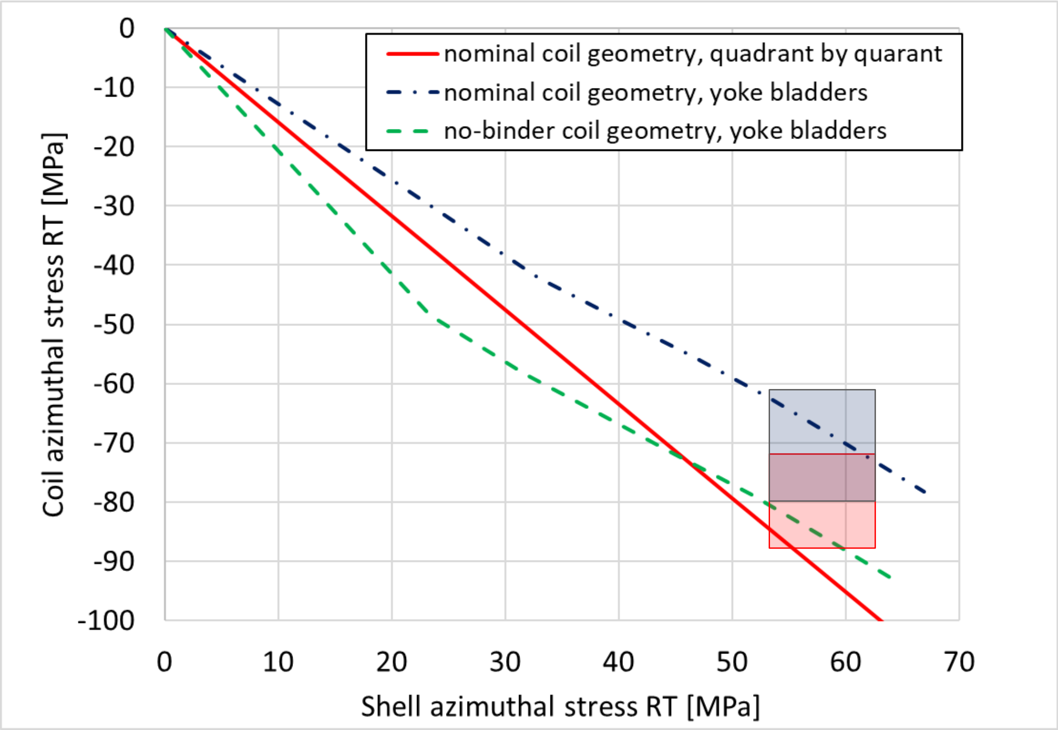
Thank you!

Additional slides

Reminder of impact on modifications in the TF

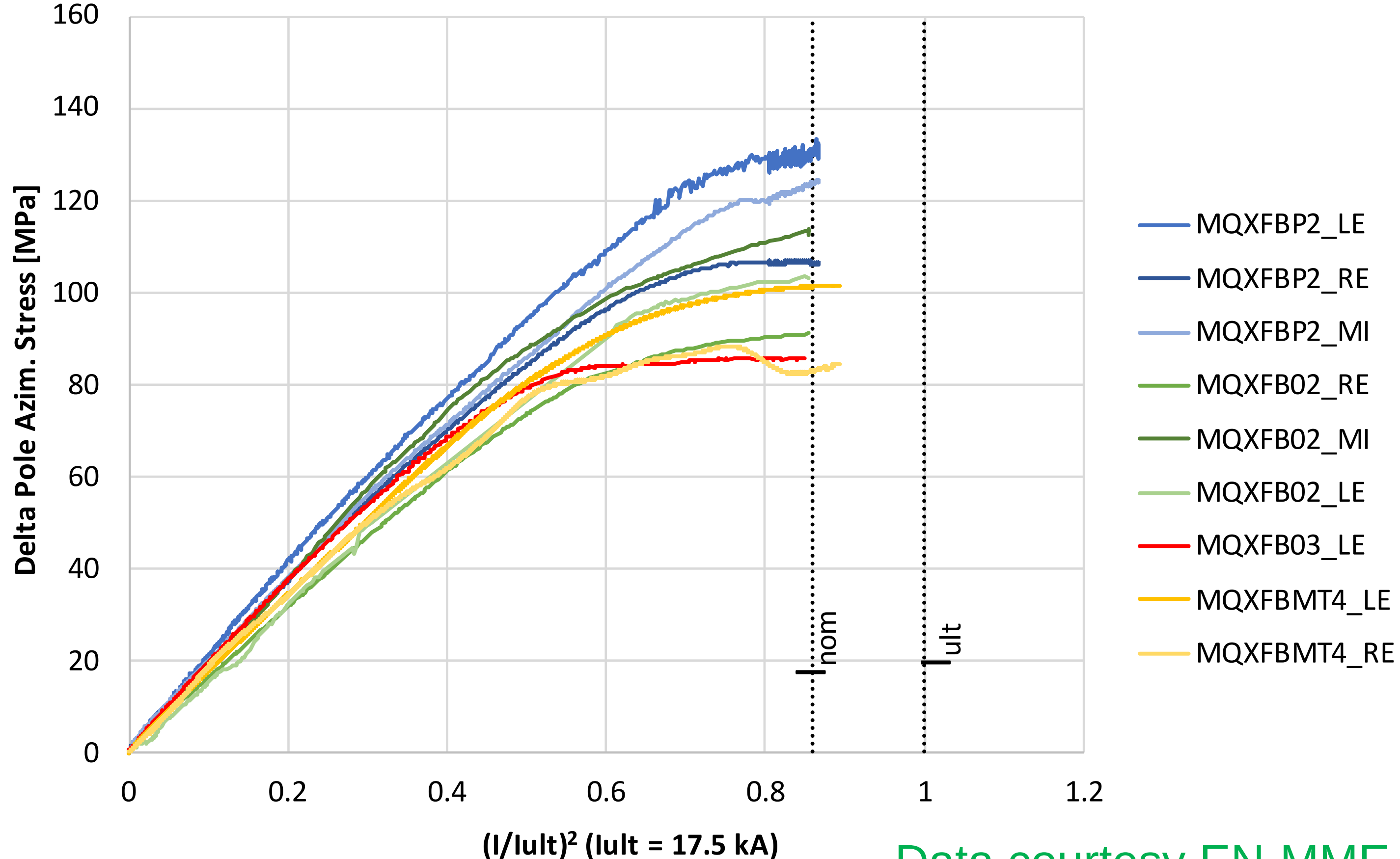
- With the new loading procedure (yoke bladders), we expect less pole stress at RT for the same shell stress → we modified the loading target in B02 to 70 +- 10 MPa (before it was 80 +- 10 MPa) (see https://indico.cern.ch/event/1158577/)

- With the new coil geometry (wedged mid-plane due to no binder in the OL), we expect 15-20 MPa more in the pole for the same shell stress (see https://indico.cern.ch/category/10520/)



Cold: Targets vs achieved

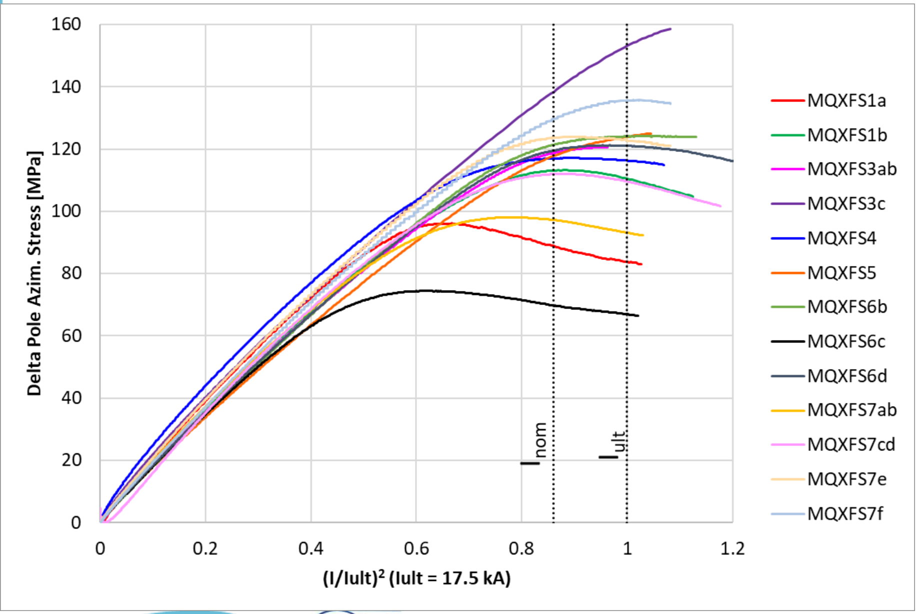
- At cold, MQXFB02 had 90-110 MPa pole azimuthal compression, corresponding to a pole un-loading around nominal current
- For MQXFB03, we only have ‘clean’ measurements from the LE end, 85 MPa.

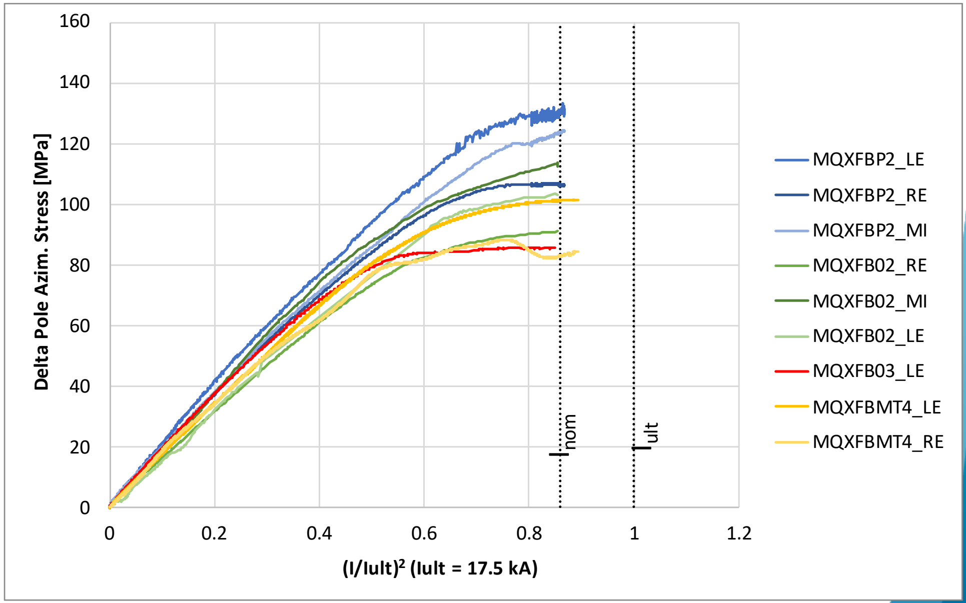


Data courtesy EN-MME

Cold: Targets vs achieved

- MQXFS explored a wide range of pre-load, with magnets reaching performance requirements with a pole azimuthal compression at cold of 70-180 MPa.
  - Low pre-load does not seem to be a limitation for performance, but might have an impact on the training (AUP has some evidences that magnets with higher pre-load train less, see Structure WG re MQXFA13 analysis and preload targets (September 5, 2023) · INDICO-FNAL (Indico))





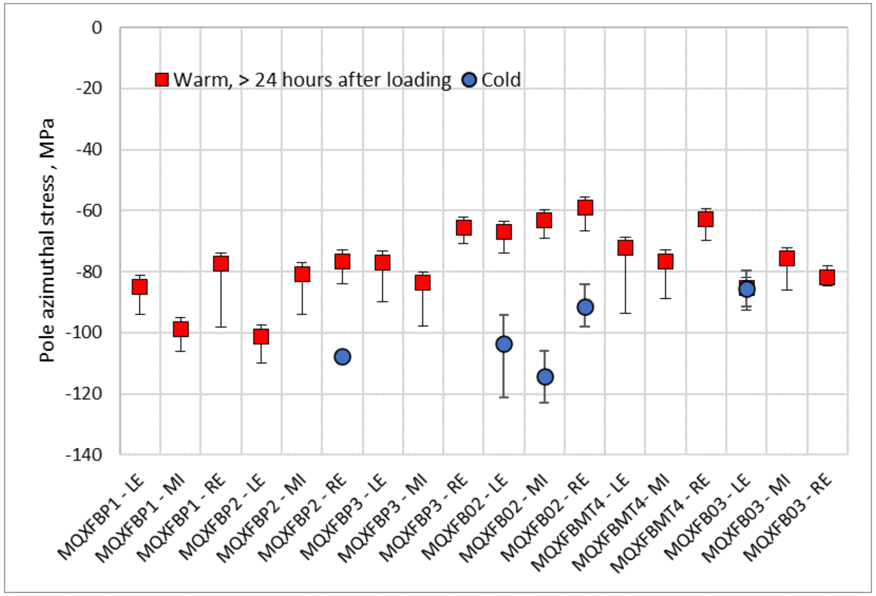
Data courtesy EN-MME

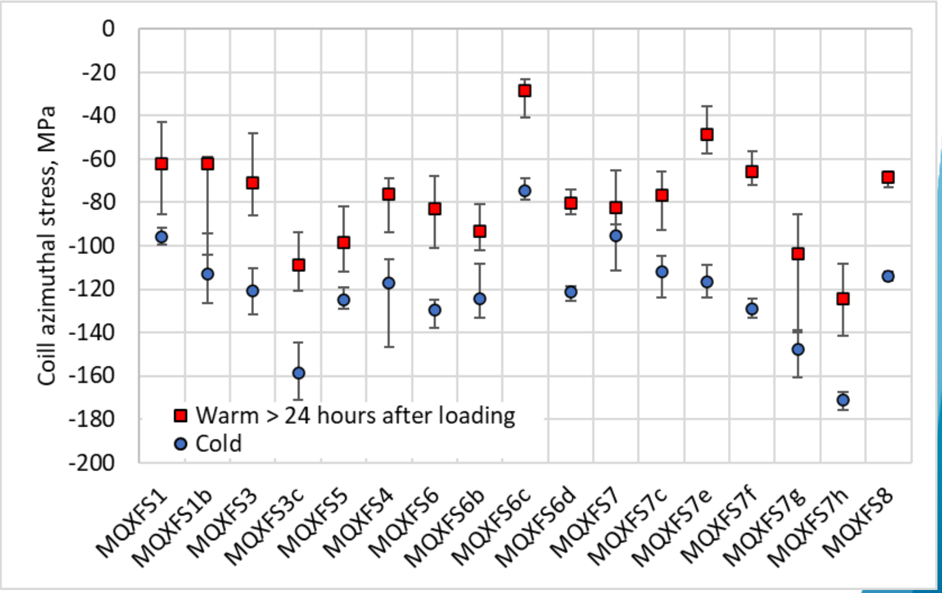
Cold: Targets vs achieved

- So far, we have very little data from B03, but we see basically no increase of the azimuthal pre-compression with the cool down (when deriving the pole compression from the delta powering)
- MQXFS explored a wide range of pre-load, with magnets reaching performance requirements with a pole azimuthal compression at cold of 70-180 MPa.

Estimated pole stress from delta powering, MPa

MQXFB03 - LE	C129	C130	C131	C128	AVE
Peak during magnet assembly	-87	-80	-63	-65	-74
> 24 hours after loading	-87	-92	-77	-86	-85
Cold	-80	-91			-85





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